S/B/N

2

AD-A255 366

FINAL TEST REPORT
FOR THE
ONBOARD SYSTEM EVALUATION OF ROTORS VIBRATION, ENGINES (OBSERVE) MONITORING SYSTEM

CONTRACT: DAAJ02-91-C-0030
DATA ITEM: A004

AUGUST 10, 1992

Approved for public release;
distribution is unlimited.

SCIENTIFIC-ATLANTA, INC.
Signal Processing Systems
13112 Evening Creek Drive South
San Diego, CA 92128-4199
(619) 679-6000
FAX: (619) 679-6008

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 1992	Final August 1991 - April 1992

4. TITLE AND SUBTITLE
On Board System for the Evaluation of Rotors, Vibration and Engines (OBSERVE)

5. FUNDING NUMBERS
C DAAJ02-91-C-0030

6. AUTHOR(S)
J. A. Goodrich
K. M. Klepin

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Scientific Atlanta
13112 Evening Creek Drive South
San Diego, CA 92128-4199

8. PERFORMING ORGANIATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Aviation Applied Technology Directorate
U.S. Army Aviation Systems Command
Fort Eustis, VA 23604-5577

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
The On Board System for the Evaluation of Rotors Engines and Vibration (OBSERVE) research and development (R&D) program was designed to investigate and demonstrate the benefits of onboard data recording/processing and rotor tuning equipment for monitoring and diagnosis of mechanical subsystems on the CH-47. The payoffs for such a concept include reduced aircraft vibration levels (with extended MTBF of electronics and mechanical systems as well as reduced crew fatigue), reduced maintenance flights, and early warning of component failures. This program demonstrates an approach to a practical, automated system which monitors certain mechanical subsystems, provides inflight vibration and control system status, and prescribes corrective actions to the maintainer. Various monitoring components were developed and integrated to demonstrate this concept.

14. SUBJECT TERMS	15. NUMBER OF PAGES	16. PRICE CODE
Diagnostics; Vibration Tuning; Engine Monitoring	19	

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

1.0 INTRODUCTION

The On Board System for the Evaluation of Rotors Vibration and Engines (OBSERVE) is a stand-alone helicopter diagnostic system based on the Army Vibration Analyzer (AVA) produced by Scientific Atlanta Inc.. The OBSERVE system was designed for the Chinook Helicopter to provide both a technology demonstrator and a platform for analyzing the cost pay back potential of on-board diagnostic monitoring technologies. This final report describes the capabilities of the OBSERVE system, the test results obtained during flight testing at Ft. Rucker, Alabama and recommendations for improvements and enhancements from both Scientific Atlanta and Army personnel conducting the flight testing.

The operation and function of the OBSERVE was successfully demonstrated during flight testing in March of 1992. Rotor induced vibration was significantly reduced in three or fewer flights. The performance of other aspects of the OBSERVE were successfully demonstrated including continuous vibration monitoring and engine monitoring. The system continues to operate and is currently installed on a CH-47D helicopter (Bearcat 2) at Ft. Rucker. The purpose of the flight testing was to demonstrate the capabilities and operation of the OBSERVE. Principally these include the following functions:

- **On Demand Rotor Track and Balance** - The system automatically detects out-of-limit vibration and track conditions caused by rotor track and balance problems and provides an on-demand measurement capability so that Rotor Track and Balance data can be collected during normal mission flights instead of dedicated maintenance flights. The goal of an on-board system is to make track and balance data easy to collect and provide automatic recommended maintenance corrections so that aircraft vibration levels can be kept at lower levels with fewer dedicated maintenance flights.

- **Oil Cooler Vibration Monitoring** - The system implements the Oil Cooler monitoring procedures TB 55-1520-240-20-51 and TB 55-1520-240-20-43 and displays exceedances on demand by the pilot. The Oil Cooler monitoring procedures define measurement setups and limits to monitor both the Aft Oil Cooler fan assembly and the shaft assembly driving the Oil Cooler Fan. The goal of this monitoring is to demonstrate the flexibility of the OBSERVE to handle known vibration monitoring and thresholding problems and eliminate the error-prone and time-consuming installation task required with the existing Oil Cooler Monitoring procedures and equipment.

- **Continuous Monitoring** - The system continuously monitors and performs vibration thresholding for selected mechanical components allowing the early detection of incipient faults prior to collateral system damage or safety problems. The pilot can trigger an on-demand acquisition and storage of collected vibration data for ground analysis of transient in-flight vibrations. The goal of this function is to demonstrate the ability of the OBSERVE to monitor and trend selected vibration components and allow an on demand data collection so that further ground analysis is easily performed on problems noticed in flight by the pilot or crew.

- **Engine Monitoring** - The system automates the turbine engine Health Indicator Test (HIT) and Turbine Engine Assurance Check (TEAC) calculations from data entered into a remote cockpit display by the pilot or copilot. It also collects engine vibration data during flight as an indicator of the need and feasibility of continuous engine vibration monitoring. The primary goal of this portion of the OBSERVE is to automate the HIT and TEAC caculations allowing a reduction in pilot workload and consistent data archiving of the HIT and TEAC results. A secondary goal is to monitor the turbine engine vibration during flight to determine if there is consistent and useful vibration information that could enhance existing engine maintenance procedures.

- **Ground Station** - The system provides a ground station capability for the storage, display and trending of collected data from the on board OBSERVE. The goal of the ground station is to demonstrate the ease of data transfer from the OBSERVE to a PC based ground station and begin a data archiving system that can be used to set additional vibration limits and investigate other mechanical problems.

2. 0 SYSTEM DESCRIPTION

This section reviews the capabilities of the OBSERVE as installed on the CH-47D helicopter, Bearcat 2, at Ft Rucker Alabama.

2.1 EQUIPMENT DESCRIPTION

The OBSERVE system is based on the Army Vibration Analyzer (AVA) developed and produced by Scientific Atlanta. An AVA system is converted to an OBSERVE system by adding new software and making minor hardware modifications within the AVA Control and Display Unit. Figure 1 provides a pictorial of the OBSERVE system. It consists of a Data Acquisiiton Unit (DAU), Control and Display Unit (CADU), Universal Tracking Devices (UTD), Remote Cockpit Display (RCD) and a PC based ground station. The function of each of the units is described below:

Data Acquisition Unit (DAU) - The DAU connects to the vibration, track and tachometer sensors and peforms the basic measurements including vibration spectrum analysis, synchronous vibration analysis used to measure amplitude and phase, and blade tracking measurements. In the continuous monitoring modes, the DAU peforms the measurement and signal thresholding. The DAU is capable of measuring data from fourteen vibration sensors, two tachometer sensors and two blade tracking sensors in it's current configuration.

Control and Display Unit (CADU) - The CADU provides data storage and a graphical user interface neccesary to display both the measured data and diagnostic information. The CADU has an interface to a Credit Card Memory (CCM) which operates similar to a disk drive, allowing the storage of data and programs. The CADU contains a database which stores measurement and diagnostic setups and measured data. The CADU controls the Remote Cockpit Display in the OBSERVE configuration, and retains all the normal AVA functions, plus the added OBSERVE capabilities.

Remote Cockpit Display (RCD) -- The RCD is a small hand held data terminal which is used to select OBSERVE operating modes, enter engine data and provides a display mechanism to the pilot and crew.

Universal Tracking Device - The UTD supplies the rotor track and balance algorithm with accurate track data and is a key element of the OBSERVE. It senses the track height automatically to approximately 1mm and blade lead-lag position to 0.2mm in all weather and light conditions. The UTD mounts on the tail and nose of the CH-47.

PC Based Ground Station - A PC based ground station allows the storage, archiveing and display of all the data types collected by the OBSERVE system. This system provides a credit card reader which allows the easy transport of the OBSERVE data from aircraft to ground station. The ground station software provides a graphical user interface based on Windows by Microsoft. This interface allows the display and comparison of multiple sets of data simultaneously.

2.2 INSTALLATION DESCRIPTION

The OBSERVE system is mounted semi-permanently on-board the CH-47. Custom brackets for the DAU, CADU and UTD have been developed. The CADU is mounted in the instrument bay, the DAU is mounted in a ceiling location near the RT&B bulkhead connector, two UTDs are mounted (one on the

nose of the aircraft and a second on the aft jacking point location). Fourteen different accelerometers are mounted throughout the CH-47 as defined in table 1. The existing RT&B accelerometers and magnetic interrupter are used as part of the equipment sensor suite.

The remote cockpit display is a small hand held device which is typically operated by the pilot or co-pilot. The cabling relies heavily on existing AVA cables which are routed and tie-wrapped to existing harnesses. The cabling can be removed without effecting the permanent aircraft wiring. Accelerometers are mounted with a variety of mounting brackets and blocks depending on the sensor location.

TABLE 1 - SENSOR LOCATIONS AND PURPOSE

Sensor Acronym	Sensor Type / Location
CBRLAT	Accelerometer - Aft Combiner Fan Lateral
CBRVRT	Accelerometer - Aft Combiner Fan Vertical
CBRLNG	Accelerometer - Aft Combiner Fan Longitudinal
AX_LAT	Accelerometer - Aft Transmission Fan Lateral
AX_VRT	Accelerometer - Aft Transmission Fan Vertical
FWDLAT	Accelerometer - Forward Rotor Head Lateral
FWDVRT	Accelerometer - Forward Rotor Head Vertical
AFTLAT	Accelerometer - Aft Rotor Head Lateral
AFTVRT	Accelerometer - Aft Rotor Head Vertical
XENG_1	Accelerometer - Engine #1 Cross Shaft
XENG_2	Accelerometer - Engine #2 Cross Shaft
FWDTRK	Tracker - Forward Head
AFTTRK	Tracker - Aft Head
ENG_1	Accelerometer - Engine #1
ENG_2	Accelerometer - Engine #2

During the installation on Bearcat 2 several cabling and sensor installation problems were discovered and resolved. Secion 4 of this report provides a list of recommendations for improving the installation process for the OBSERVE.

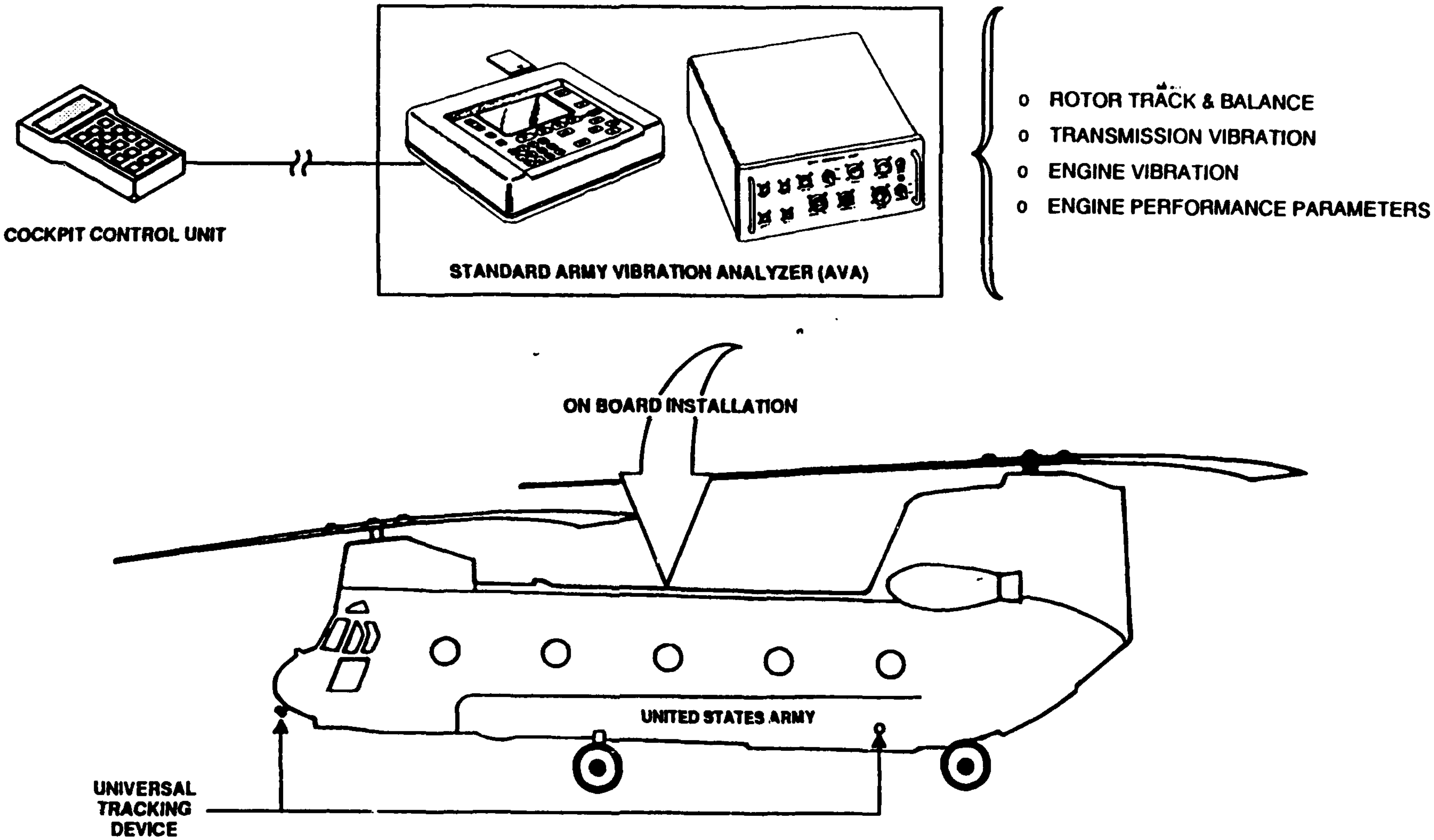
3.0 FLIGHT TEST RESULTS

3.1 ON-DEMAND ROTOR TRACK AND BALANCE RESULTS

The OBSERVE goal for on board rotor track and balance is to allow the pilot or crew to easily collect rotor track and balance data during normal flights and to produce corrective actions that reduce vibration and track splits below specified limits with a minimum number of dedicated maintenance flights. During flight tests this capability was demonstrated by tuning the helicopter prior to and after seeding rotor faults on the aircraft and allowing the OBSERVE to recommend corrective actions.

Prior to seeded fault tests, this capability was also successfully demonstrated when the "as delivered" Bearcat 2 showed over limit vibration and track split levels. Table 2 provides a listing of the baseline data from the test center (shown in the Delivered Condition column) and the baseline and correction flight data generated by the OBSERVE system.

ONBOARD SYSTEM FOR EVALUATION OF ROTORS, VIBRATION & ENGINES (OBSERVE)



6/2/92

Figure 1 - Pictorial of OBSERVE System

PRE-SEEDED FAULT TESTING

Prior to seeding faults on Bearcat 2, a check flight was required to verify the performance of the seat absorber. During this check flight the pilot made measurements with the OBSERVE system to get the feel of its operation. This initial data is found in appendix A with a time stamp of March 26, 1992 at 11:27. It indicated vibration levels up to 0.86 IPS for forward vertical measurements. This data is not included in the table 2 because measurements were not taken at the appropriate flight conditions. However, this prompted the collection of a baseline set of data with the OBSERVE system indicated as Baseline Flight #1.

The Baseline flight #1 shows that Bearcat 2 was not in a proper rotor track and balance condition and the measurements varied significantly from those reported by the test center. This prompted the use of the OBSERVE system to smooth the aircraft prior to fault seeding. The vibration levels after the smoothing are shown in the flight #4 column. The aircraft was smoothed substantially below the 0.2IPS recommendations over the entire flight profile, using three sets of corrections and four flights.

TABLE 2 - ROTOR TRACK AND BALANCE VIBRATION RESULTS PRE-SEEDED FAULT FLIGHTS

Flight Condition	Delivered Condition		Baseline Flight #1 3/26/92 15:15		Flight #2 3/26/92 17:42		Flight #3 3/27/92 10:37		Flight #4 3/27/92 11:57	
HOVER	IPS	Clock	IPS	Degrees	IPS	Degrees	IPS	Degrees	IPS	Degrees
Forward Lateral	0.160	8:26	0.47	258	0.24	137	0.17	229	0.13	201
Forward Vertical	N/A		0.19	144	0.07	153	0.08	141	0.08	154
Aft Lateral	0.114	2:35	0.16	109	0.14	174	0.20	117	0.20	113
Aft Vertical	N/A		0.16	322	0.08	209	0.04	237	0.03	280
Track Split Forward	N/A		2.6"		1.6"		2.3"		0.9"	
Track Split Aft	N/A		0.4"		0.4"		0.4"		0.4"	
60/80KNTS										
Forward Lateral	0.111	8:35	0.10	217	0.17	104	0.05	15	0.08	201
Forward Vertical	0.275	2:17	0.51	149	0.28	158	0.23	135	0.13	124
Aft Lateral	0.131	10:16	0.13	17	0.07	0	0.08	57	0.10	47
Aft Vertical	0.059	10:23	0.16	322	0.02	98	0.08	131	0.09	138
Track Split Forward	N/A		2.0"		0.3"		0.4"		0.5"	
Track Split Aft	N/A		1.8"		0.6"		0.6"		0.3"	
120 KNTS										
Forward Lateral	N/A		0.32	258	0.21	137	0.08	201	0.05	160
Forward Vertical	N/A		0.60	157	0.30	173	0.28	150	0.16	151
Aft Lateral	N/A		0.08	42	0.01	347	0.08	111	0.10	104
Aft Vertical	N/A		0.29	328	0.03	105	0.11	106	0.09	115
Track Split Forward	N/A		3.9"		1.3"		2.0"		0.5"	
Track Split Aft	N/A		1.1"		0.5"		0.9"		1.3"	
135/ 140KNTS										
Forward Lateral	0.056	5:11	0.45	275	0.15	112	0.09	221	0.07	181
Forward Vertical	0.141	2:58	0.62	145	0.27	171	0.22	144	0.03	307
Aft Lateral	0.058	11:54	0.13	54	0.04	206	0.07	114	0.14	114
Aft Vertical	0.146	11.27	0.48	214	0.11	347	0.09	323	0.09	15
Track Split Forward	N/A		3.3"		1.3"		1.3"		1.2"	
Track Split Aft	N/A		1.1"		1.3"		0.4"		1.9"	

The aircraft had a history of requiring excessive balance weights, probably due to either a heavy blade or blade chord wise balance problem. The baseline data was used to generate an initial set of diagnostic corrections that resulted in a solution requiring weight to be subtracted from both the RED and YELLOW blades or be added to the GREEN blade on the forward head. This adjustment was not physically possible on the aircraft, so the RESOLVE TO LIMIT and BEST N diagnostic modes were used to generate the recommended corrections.

The OBSERVE system has three diagnostic software modes to create alternative diagnostic solutions when certain adjustments are not possible. These three features are:

1) **EDIT ADJUSTABLES** - Allows the disabling or enabling of any possible adjustment location or type. For example forward head weights can be turned off, resulting in the best corrections without adjusting forward rotor weights.

2) **BEST N** - Allows the user to enter the number N where N is the maximum number of corrections allowed by the OBSERVE diagnostic system. For example, N=1 will result in the single best correction for the rotor system. The objective of BEST N is to generate the lowest number of corrections possible to smooth the aircraft, thereby reducing the workload and potential for erroneous installation.

3) **RESOLVE TO LIMIT** - Forces the diagnostics to select corrections that drive the vibration to 0.2 IPS rather than to zero. for all measurements. This mode discounts the effects of track and trades off vibrations significantly lower than 0.2 IPS to get all vibration readings equal to or just below 0.2 IPS.

TABLE 3 PRE-SEEDED FAULT RECOMMENDED CORRECTIONS

RECOMMENDED ADJUSTMENT	After Baseline Flight #1 3/26/92 15:15			After Flight #2 3/26/92 17:42			After Flight #3 3/27/92 10:37		
	GREEN	YELLOW	RED	GREEN	YELLOW	RED	GREEN	YELLOW	RED
Fwd Weights (weights)				0	-5	-3			
Fwd Pitch Links (notches)	0	+8	0	+7	0	-2			
Fwd Tabs (degrees)				0	+2	+0.5		+1	
Aft Weights (weights)				0	0	-1			
Aft Pitch Links (notches)	-1	+1	0	0	+4	0			
Aft Tabs (degrees)	0.5	0	-0.5	0	-3.5	0			
COMMENTS	Couldn't install weights on the forward head so Best N and Resolve to Limits used to eliminate weight adjustments that allowed track split to compensate for weight balance.			Default solution used in this case. All weight adjustments were possible except RED blade weight. Track split improvement dominant for this solution, minimal vibration improvements.			Default solution provided recommended weight corrections that could not be installed on the rotor system. Best N=6 and Resolve to Limits used to generate this correction.		

The results of the first correction set showed dramatic vibration reductions in both Hover forward lateral and forward verticals in all the flight conditions. The largest vibration reading was 0.3 IPS for the 120KNTS forward vertical vibration, and the maximum track split was 1.6". This represents a substantial improvement over the 0.6 IPS vibration readings and 3.9" track splits recorded during the baseline flight.

However, these results were not within the 0.2 IPS vibration limits, so a second set of corrections were generated using the Flight #2 data using standartd diagnostics rather than BEST N or RESOLVE TO LIMITS. These corrections lowered some of the highest vibrations but did not substantially improve the smoothness of the rotor system. It is believed that reducing the track split was the dominant action of correction set two. Because it is substantially harder to install seven adjustments accurately, a third set of corrections were installed in the rotor system. For this set of corrections the BEST N and RESOLVE TO LIMITS features were used resulting in a single tab correction on the forward head. The vibration smoothing results were impressive, with all vibration readings at or under the 0.2 IPS recommendation and many under 0.1 IPS. The comments from the pilot and crew confirmed the smoothness of the aircraft. There was still a track split of approximately 1" which was probably counterbalancing the heavy blade or chord wise balance problem.

SEEDED FAULT TESTING

After Flight #4 it was possible to install seeded faults of the rotor system. An adjustment was made to the forward RED pitch control rod of -12 notches. The OBSERVE system was operated in the AUTOMATIC MODE which automatically performs limits checking for track splits greater than 1" and vibrations readings greater than 0.5 IPS for both lateral and vertical vibrations on the forward and aft rotor head. Data from the seeded fault testing is found in Table 4.

Data was collected at FPG100 and HOVER conditions after the -12 notch correction. Collected data showed a greater than 1.0 IPS vibration and a large track split so that only those two conditions were collected. The seeded fault produced a 1.19 IPS vibration at hover so forward flight data was not collected. The seeded fault value was reduced from -12 notches to -6 notches. Data was then collected over the entire flight profile as shown in Flight #6.

The flight #6 data shows that forward rotor vertical vibrations were as high as 0.51 IPS at 140KNTS and typically over the 0.2 IPS limit. The track split at hover on the forward rotor head was 4.3" which is consistent with the seeded fault. The recommended corrective actions included a +10 notch adjustment in the RED forward PC link along with AFT weight changes (see Table 5). It is significant to note that only two corrections were recommended even though the BEST N value was set at 5. The BEST N and RESOLVE TO LIMIT combination attempts to provide the minimum number of corrections to achieve the 0.2 IPS vibration goal. This recommended set primarily targeted the seeded fault location (which is to be expected.)

The recommended corrections resulted in three vibrations over the 0.2 IPS limit (0.22 IPS for the HOVER AFT lateral and 0.22 IPS and 0.23 IPS for the 80KNTS and 120KNTS forward flight conditions), and was a very good solution. One additional set of corrections was generated to determine if all the vibrations could be reduced below 0.2 IPS. A BEST N=1 and RESOLVE TO LIMITS diagnostic mode was used to generate the single best correction.

The OBSERVE system recommended a single 1 degree tab adjustment in the forward head YELLOW blade. The tab correction was installed and the aircraft was flown on Flight #8. The flight data shows that the aircraft vibration data was below 0.2 IPS for all flight conditions. In many cases the vibration was below 0.1 IPS. This was an extremely smooth Chinook. The results of the seeded fault testing clearly showed that the OBSERVE system performed rotor track and balance very well on a difficult aircraft.

TABLE 4 - ROTOR TRACK AND BALANCE VIBRATION RESULTS SEEDED FAULT FLIGHTS

FLIGHT CONDITION	Flight #4 3/27/92 10:37	Flight #5 3/27/92 13:59 Seeded Fault #1	Flight #6 3/27/92 15:38 Seeded Fault #2	Flight #7 3/27/92 16:58	Flight #8 3/30/92 11:44
HOVER					
Forward Lateral	0.13 201	1.19	0.5 164	0.12 257	0.02 219
Forward Vertical	0.08 154	0.38	0.18 34	0.06 130	0.05 155
Aft Lateral	0.20 113	0.12	0.17 85	0.22 106	0.16 162
Aft Vertical	0.03 280	0.39	0.19 230	0.06 305	0.06 205
Track Split Forward	0.9"	2.7"	4.3"	0.7"	0.7"
Track Split Aft	0.4"	0.6"	0.7"	0.4"	0.9"
60/80KNTS					
Forward Lateral	0.08 201	N/A	0.17 128	0.12 335	0.14 16
Forward Vertical	0.13 124	N/A	0.43 53	0.22 111	0.10 153
Aft Lateral	0.10 47	N/A	0.13 18	0.16 63	0.12 310
Aft Vertical	0.09 138	N/A	0.29 215	0.05 287	0.10 167
Track Split Forward	0.5"	N/A	2.4"	0.4"	0.5"
Track Split Aft	0.3"	N/A	0.7"	0.2"	0.7"
120 KNTS					
Forward Lateral	0.05 160	N/A	0.26 141	0.04 91	0.11 349
Forward Vertical	0.16 151	N/A	0.43 40	0.23 124	0.16 212
Aft Lateral	0.10 104	N/A	0.09 50	0.11 61	0.08 267
Aft Vertical	0.09 115	N/A	0.35 209	0.09 283	0.11 125
Track Split Forward	0.5"	N/A	3.6"	1.6"	1.2"
Track Split Aft	1.3"	N/A	1.2"	0.5"	0.4"
135/ 140KNTS					
Forward Lateral	0.07 181	N/A	0.49 146	0.11 334	0.14 23
Forward Vertical	0.03 307	N/A	0.51 16	0.15 255	0.15 255
Aft Lateral	0.14 114	N/A	0.07 54	0.14 77	0.08 231
Aft Vertical	0.09 15	N/A	0.48 229	0.17 298	0.06 87
Track Split Forward	1.2"	N/A	2.4"	2.3"	0.8"
Track Split Aft	1.9"	N/A	1.2"	0.3"	0.16"

TABLE 5 SEEDED FAULT RECOMMENDED CORRECTIONS

RECOMMENDED ADJUSTMENT	After Baseline Flight #6 GREEN	YELLOW	RED	After Baseline Flight #7 GREEN	YELLOW	RED
Fwd Weights (weights)	0	0	1	0	0	0
Fwd Pitch Links (notches)	0	0	10	0	0	0
Fwd Tabs (degrees)	0	0	0	0	1	0
Aft Weights (weights)	0	0	0	0	0	0
Aft Pitch Links (notches)	0	0	3	0	0	0
Aft Tabs (degrees)	0	0	0	0	0	0
COMMENTS	Due to the large track split in the smooth condition the diagnostics were run with BEST N=5 and RESOLVE TO LIMITS to avoid trading off track for reduced vibration			To trim the last vibration out, BEST N=1 and RESOLVE TO LIMITS was used. A single tab adjustment made the aircraft extremely smooth.		

PARTIAL DATA SET CORRECTIONS

During seeded fault testing a large seeded fault of 12 notches was made in a PC link. This resulted in a high vibration that prevented the data collection over any forward flight conditions. This situation is not uncommon when an aircraft can be severely mis-adjusted after rotor maintenance, and it provided a very good opportunity to test the OBSERVE system on partial data sets. The tables 6 and 7 demonstrate OBSERVE's capability to do this.

The second column in each table shows the recommended corrections based on the smooth baseline from Flight #4. The third column shows the corrections expected to counteract the seeded fault and those corrections recommended from Flight #4. The fourth column of each table shows the actual recommended corrections. The data was collected in a flight plan reserved for forward flight, which normally includes tab adjustments as part of the recommended corrections. For the FPG100 and HOVER test conditions tab adjustments are not appropriate, so they were removed from consideration by using the EDIT ADJUSTABLES capability of the OBSERVE.

TABLE 6 - RECOMMENDED CORRECTIONS FROM FLIGHT #5 PARTIAL DATA SET FOR FPG100

RECOMMENDED ADJUSTMENT FROM FLIGHT #5 PARTIAL DATA SET FPG100	Recommended Corrections from Flight #4			Expected Corrections resulting from baseline and seeded fault			Actual Recommended Corrections		
	GREEN	YELLOW	RED	GREEN	YELLOW	RED	GREEN	YELLOW	RED
Fwd Weights (weights)	0	1	2	0	1	2	0	-1	-1
Fwd Pitch Links (notches)	0	-1	2	0	-1	14	-3	0	16
Fwd Tabs (degrees)									
Aft Weights (weights)	0	3	1	0	3	1	0	3	1
Aft Pitch Links (notches)	0	0	-2	0	0	-2	0	0	1
Aft Tabs (degrees)									
COMMENTS	These are the recommended corrections using the diagnostics on Flight #4 data with the tabs turned off.			These are the expected corrections when the default corrections combine with the seeded fault of -12 notches on FWD RED PC link.			Analysis • Large upward correction picked up for FWD RED PC link • Picked up all aft weight changes		

The recommended corrections based on the FPG100 data removed the forward PC link seeded fault and included the AFT weight changes resulting from the baseline flight. These corrections would have significantly reduced vibration levels in the aircraft allowing forward flight.

The recommended corrections based on the HOVER data were less impressive. The diagnostics removed the seeded fault but added weight on both the forward and aft heads that would have been removed during later flights.

TABLE 7 - RECOMMENDED CORRECTIONS FROM FLIGHT #5 PARTIAL DATA SET FOR HOVER

RECOMMENDED ADJUSTMENT FROM FLIGHT #5 PARTIAL DATA SET HOVER	Recommended Corrections from Flight #4			Expected Corrections resulting from baseline and seeded fault			Actual Recommended Corrections		
	GREEN	YELLOW	RED	GREEN	YELLOW	RED	GREEN	YELLOW	RED
Fwd Weights (weights)	0	1	2	0	1	2	0	6	0
Fwd Pitch Links (notches)	0	-1	2	0	-1	14	-8	0	17
Fwd Tabs (degrees)									
Aft Weights (weights)	0	3	1	0	3	1	0	4	-10
Aft Pitch Links (notches)	0	0	-2	0	0	-2	0	6	-1
Aft Tabs (degrees)									
COMMENTS	These are the recommended corrections using the diagnostics on Flight #4 data with the tabs turned off.			These are the expected corrections when the default corrections combine with the seeded fault of -12 notches on FWD RED PC link.			Analysis • Large upward correction picked up for FWD RED PC link • Shows significant interaction between fwd and aft rotors.		

KEY POINTS

- **ACCURACY OF MEASUREMENT EQUIPMENT** - The aircraft was delivered from maintenance with the vibration measurements listed in table 2 column 1. These measurements were taken with other equipment and were significantly lower than the baseline data taken by the OBSERVE during flight #1 before corrective actions or seeded faults were installed. The OBSERVE/RADS AT accuracy is traceable to the National Bureau of Standards. When considering vibration limits the accuracy and repeatability of the measurement equipment is extremely important. The lack of measurement system accuracy should not dictate the measurement thresholds and maintenance actions.

- **OBSERVE RT&B RESULTS** - The OBSERVE performed rotor track and balance very successfully for both seeded and non-seeded fault testing. In each case the vibration levels were reduced below the 0.2 IPS threshold in three flights or less. The OBSERVE system automatically calculated the recommended corrections, which were then installed on the aircraft.

- **SINGLE SHOT CORRECTIONS** - In both seeded and non-seeded fault testing the aircraft was brought very close to limits with a single set of corrections. Corrective actions were generated using the single shot diagnostics of the OBSERVE/RADS-AT, which smoothed the aircraft over the entire flight profile with a single set of recommended corrections.

- SHORT DATA COLLECTION TIME - The flight time required to collect vibration and track data was approximately 1 minute and 40 seconds per test condition or less than seven minutes for the entire flight profile. All data was automatically collected after the pilot selected the test condition. This is significant, because one of the goals of the OBSERVE is to reduce dedicated maintenance test flights.

3.2 OIL COOLER VIBRATION MONITORING TEST RESULTS

The goal of Oil Cooler Vibration Monitoring is to demonstrate the flexibility of the OBSERVE to handle known vibration monitoring and thresholding problems and eliminate the error prone and time consuming installation task required with the existing Oil Cooler Monitoring procedures and equipment.

Accelerometers and brackets were installed on the AFT transmission to monitor the combiner fan and associated shaft vibrations. The fan vibrations were acquired with both continuous and pilot initiated monitoring using the OBSERVE system. The fan vibration components were all within specification as expected. Seeded faults were not installed on the Fan due to safety considerations.

Pilot initiated Oil Cooler vibration monitoring tests were conducted during initial aircraft baselining. Data from these measurements can be found in Appendix A in "SAVED EVENT MODE" and "SPECTRAL DATA" sections.

For pilot initiated testing, the pilot selected the MAINTENANCE MODE - 50 HOUR test option on the remote cockpit display. The pilot was presented with two test state options (OILCLR and AFTFAN). Both options were selected. The OBSERVE system automatically measured the required accelerometer channels and compared the measured vibration with pre-selected limits based on the test procedures TB 55-1520-240-20-40 and TB 55-1520-240-20-51. The remote cockpit display indicated that no exceedances were detected. Table 8 provides a summary of the pre-defined limits and measured data.

TABLE 8 - RESULTS OF THE OIL COOLER VIBRATION MONITORING

SENSOR	LIMIT	MEASURED DATA
Combiner Fan Lateral @ 115.2 HZ	0.5 IPS	0.009 IPS
Combiner Fan Lateral @ 162.3 HZ	0.2 IPS	0.036 IPS
Combiner Fan Lateral @ 204.4 HZ	1.0 IPS	0.032 IPS
Combiner Fan Vertical @ 115.2 HZ	0.5 IPS	0.023 IPS
Combiner Fan Vertical @ 162.3 HZ	0.2 IPS	0.011 IPS
Combiner Fan Vertical @ 204.4 HZ	1.0 IPS	0.209 IPS
Combiner Fan Horizontal @ 115.2 HZ	0.5 IPS	0.013 IPS
Combiner Fan Horizontal @ 162.3 HZ	0.2 IPS	0.068 IPS
Combiner Fan Horizontal @ 204.4 HZ	1.0 IPS	0.198 IPS
AFT XMSN Fan Vertical @ 175.3 HZ	0.7 IPS	0.083 IPS
AFT XMSN Fan Lateral @ 175.3 HZ	0.7 IPS	0.202 IPS

The Oil Cooler vibration measurement and thresholding is included in the Continuous Monitoring Mode. Measurents and thresholding were continuously performed and no exceedances were reported on the Oil Cooler or Shaft assembly. However, the Continuous Mode stores component data from all thresholded components whenever there is a limit exceeded or a pilot iniated "SAVE EVENT". Oil Cooler data collected in this mode is available in Appendix A section "SAVE EVENT MODE". This data was a result of both an automatic limit exceedance from large track splits and pilot initiated save events. Data is time and date tagged and is saved from several different flights.

KEY POINTS

- **ON DEMAND MONITORING** - The pilot and crew were able to easily determine the vibration status of the Oil Cooler Fan. Measurements and thresholding were automatically conducted giving the pilot a vibration status on demand.
- **CONTINUOUS MONITORING** - The Oil Cooler components were continuously monitored when the OBSERVE was in the continuous monitoring mode.
- **EASE OF USE** - Both the on demand and continuous modes were operated through the remote cockpit display. A few key sequences selected the operation. Installing and removing sensors and cables was not an issue once the system was permanently installed.

3.3 CONTINUOUS MONITORING TEST RESULTS

The Continuous Monitoring mode allows automatic measurement and thresholding of vibration and track data during the operation of the aircraft. The pilot selects this mode once during aircraft startup and monitoring continues automatically until aircraft power is shut down or the pilot selects an alternate operating mode. Critical monitoring is performed which allows an in flight indication of aircraft status on demand, or a status indication to maintenance personnel once the aircraft has landed.

The pilot has the option of initiating a storage of the data used for exceedance monitoring by selecting the SAVE EVENT mode. The SAVE EVENT mode was not tested due to flight time limitations.

The OBSERVE system was configured to monitor and threshold components listed in table 9. The selection of components is completely configureable using a personal computer and additional components and threshold are easily added.

TABLE 9 - CONTINUOUS MONITORING SETUPS

COMPONENT NUMBER	DESCRIPTION	LIMIT
1	Track Split All Flight Conditions	1.0"
2	Forward Lateral Main Rotor Vibration All Flight Conditions	0.5 IPS
3	Forward Vertical Main Rotor Vibration All Flight Conditions	0.5 IPS
4	AFT Lateral Main Rotor Vibration All Flight Conditions	0.5 IPS
5	AFT Vertical Main Rotor Vibration All Flight Conditions	0.5 IPS
6	Combiner Fan Lateral @ 115.2 HZ	0.5 IPS
7	Combiner Fan Lateral @ 162.3 HZ	0.2 IPS
8	Combiner Fan Lateral @ 204.4 HZ	1.0 IPS
9	Combiner Fan Vertical @ 115.2 HZ	0.5 IPS
10	Combiner Fan Vertical @ 162.3 HZ	0.2 IPS
11	Combiner Fan Vertical @ 204.4 HZ	1.0 IPS
12	Combiner Fan Horizontal @ 115.2 HZ	0.5 IPS
13	Combiner Fan Horizontal @ 162.3 HZ	0.2 IPS
14	Combiner Fan Horizontal @ 204.4 HZ	1.0 IPS
15	AFT XMSN Fan Vertical @ 175.3 HZ	0.7 IPS
16	AFT XMSN Fan Lateral @ 175.3 HZ	0.7 IPS

Sixteen different components are monitored in a round-robin monitoring loop and the most recent sixteen component values from the measurement are stored in temporary memory. When an exceedance occurs the most recent sixteen data values from each monitored point are automatically stored for later ground analysis.

Vibration components can be monitored either on a fixed threshold and/or vibration rate of change basis. The rate at which components are monitored is controlled by a parameter defining the number of times the loop must execute before that specific threshold is performed. False alarms are controlled by both the proper selection of limits and a parameter which defines the number of times an exceedance must occur before a limits flag is sent to the remote cockpit display and the data automatically stored.

Data can be found in Appendix A for a flight on March 30, 1992 at approximately 13:07. Data from each of the measured points is available. The data was automatically collected because a track split went out-of-limits and was detected by the OBSERVE system. A complete round robin measurement cycle as configured requires approximatley 3.5 minutes to complete. On long flights many cycles would be measured and thresholded. On the short flights used during this test, the measurement cycle was completed only two to three times.

KEY POINTS

- **CONTINUOUS MONITORING** - The continuous monitoring mode worked successfully during flight test. It detected track split faults and stored complete data ensembles.

- **MONITORING TIME** - Measurement of 16 different components required approximately three and one half minutes to complete.

3.4 ENGINE MONITORING TEST RESULTS

The goal of the OBSERVE Engine Monitoring function is to calculate values for the Health Indicator Test (HIT) and Turbine Engine Assurance Check (TEAC) and demonstrate the ability to monitor and trend selected engine vibration components. The OBSERVE system required the installation of high temperature accelerometers on each engine. Cockpit instrument readings were used as input for the HIT and TEAC checks.

The HIT and TEAC calculation feature was first validated by the pilots using data entries from their log books. The HIT check calculation matched the calculation from the pilot log book. The TEAC showed one engine a degree high which also matched the log book. The ground check indicated succesfull operation of this feature.

The HIT and TEAC modes are selected by entering the Maintenance mode on the remote cockpit display. Once in the maintenance mode the Engine check feature is selected. Either a HIT or a TEAC can be calculated. The pilot reads the temperature and speed data from his cockpit instruments and enters this data into the RCD. The HIT and TEAC values are automatically calculated and displayed to the pilot. This frees him from doing the chart lookups and data logging of the existing procedure. A complete data set is stored for later retrieval from the ground station.

The data from the HIT and TEAC is available in Appendix A in the Maintenance Mode HIT/TEAC data section. The data section includes a log of the entered data, time and data, free air temperature %N1 and the HIT value.

Vibration data from both engines was collected. Table 9 provides the measured vibration peaks and associatted frequencies. The vibration monitoring of the engines was only done on a cursory basis due to the limited flight time and the time required to smooth the aircraft prior to seeded fault testing.

TABLE 9 - ENGINE VIBRATION DATA

FREQUENCY	ENGINE #1	ENGINE #2
1950 RPM	0.09 G	0.02 G
12262 RPM	0.21 G	0.14 G
14890 RPM	0.20 G	1.27 G

It is significant to note that the vibration reading at 14890 RPM on engine #2 is significantly higher than engine 1.

KEY POINTS

- HIT/TEAC - The HIT and TEAC features of the OBSERVE system were succesfully demonstrated.

- ENGINE VIBRATION - Vibration measurements were made on the engines. More time is needed to determine if engine vibration monitoring can be an effective maintenance tool.

3.5 GROUND STATION TEST RESULTS

A ground station was provided as part of the OBSERVE system. The ground station contains a software package developed by Scientific Atlanta called HGAS (Helicopter Ground Analysis Software). This software package contains a data base and graphical user interface based on the Windows operating system from Microsoft Corporation. The ground station software is under development at Scientific Atlanta using internal research and development funds.

It is capable of archiving and displaying all the OBSERVE data types and was used extensively to develop this test report. The OBSERVE data was collected and stored on a 2 Mbyte Credit Card Memory (CCM). The CCM was removed from the OBSERVE CADU and installed in the ground station at the end of flight testing. The data was copied from the CCM to the HGAS database and was available for display and analysis. The data found in Appendix A was printed using the ground station. Several annotation problems were discovered when using the ground station including improper title and time annotation. These are being corrected.

4.0 RECOMMENDATIONS / OBSERVATIONS

This section contains a summary of recommendations from the Army personnel and Scientific Atlanta personnel involved with the OBSERVE testing and documentation.

1. The installation of the OBSERVE Data Acquisition Unit (DAU) in the ceiling makes cabling very difficult due to poor access.

2. The engine drive shaft output pinion accelerometers have clearance problems with the particle separators. The right engine accelerometer was moved to the 3 o' clock position from the 12 o' clock position. The left engine accelerometer was moved to the 9 o' clock position.

3. It was recommended that a bulkhead connector be installed above the water line to allow easy connection of the AFT Tracker on permanent installations. This prevents damage to the tracker cable when the door is operated.

4. The crew felt that the AFT Tracker location would be used as a step causing damage to the UTD. They recommend using one of the mounting locations available after the old antenna was removed. This position is directly up from the current location.

5. One of the pilots recommended that an option be available to review the measured data even though a limits exceedance has not occurred.

6. A "DONE" indication was appearing on the RCD when the track measurement was made on the forward head before the track measurements were complete on the AFT head. This was causing confusion. The pilot recommended that the system have this temporary statement removed and not indicate DONE until both the measurement are complete.

7. Scientific Atlanta recommends running the diagnostics with the BEST N=6 and RESOLVE TO LIMITS features set as defaults to reduce the number of recommended corrections.

8. The pilot and crew felt that some of the labels defining the test states were not commonly used in the Army.

9. It was noted that no data is collected unless there is an exceedance. The pilot and crew recommended there be a time based exceedance. For example if after seven days no data had been collected that a full suite be automatically collected and stored.

10. Fix the data labeling and time stamp bugs on the ground station.

5.0 CONCLUSIONS

The goals of the OBSERVE system are to supply an economical on-board technology demonstrator which can be used to demonstrate the cost pay back potential of on-board monitoring systems. These goals were accomplished and demonstrated during flight tests conducted at Ft Rucker, Alabama. The OBSERVE flight testing demonstrated:

1. An on-demand rotor track and balance system which can easily collect RT&B data during normal mission flights without increasing pilot workload.

2. A vibration monitoring system which simplifies and automates the CH-47 Oil Cooler Monitoring procedures.

3. A continuous monitoring system which can easily be configured to monitor different vibration components with a very flexible limits checking capability.

4. A system which automates the table look up and archiving procedures for the Turbine Engine Assurance Checks (TEAC) and Health Indicator Test (HIT) including vibration monitoring of the engines in flight.

5. A ground station capable of reading the OBSERVE credit card memories, archiving and displaying collected data in a PC based Windows environment.

The OBSERVE performed rotor track and balance very successfully for both seeded and non-seeded fault testing. In each case the vibration levels were reduced below the 0.2 IPS threshold in three flights or less. The OBSERVE system automatically calculated the recommended corrections which were installed in the aircraft. In both seeded and non-seeded fault testing the aircraft was brought very close to limits with a single set of corrections. Corrective actions were generated using the "Single Shot" diagnostics of the OBSERVE/RADS AT which smoothed the aircraft over the entire flight profile simultaneously producing corrections for pitch control rods, tabs and weights.

The flight time required to collect vibration and track data was approximately 1 minute and 40 seconds per test condition or less than seven minutes for the entire flight profile. All data was automatically collected after the pilot selected the test condition. This is significant because one of the goals of the OBSERVE is to reduce dedicated maintenance test flights.

The pilot and crew were able to easily determine the vibration status of the Oil Cooler Fan. Measurements and thresholding were automatically conducted giving the pilot a vibration status on demand. The Oil Cooler components were continuously monitored with the OBSERVE in the continuous monitoring mode. Both the on demand and continuous modes were operated through the remote cockpit

display. A few key sequence selected the operation. Installing and removing sensors and cables was not an issue once the system was permanently installed. Measurement of 16 different components required approximately three and on half minutes to complete.

The HIT and TEAC features of the OBSERVE system were successfully demonstrated. Vibration measurements were made on the engines in flight. More effort is needed to determine if engine vibration monitoring can be an effective maintenance tool.

The OBSERVE system was developed as a general monitoring system based on the Army Vibration Analyzer (AVA). Software enhancements and minor hardware modifications are all that is required to convert an AVA into an OBSERVE. Most aircraft type-specific setup and diagnostic information is controlled via a script file. This script file can be edited on a personal computer with a text editor. The OBSERVE can be easily modified in the field to monitor new components or be adapted to different aircraft types.

Hardware and software expansions are under development to extend the capabilities of the AVA and OBSERVE. A list of recommended modifications has been provided in section 4.0. The extension of mechanical diagnostics is an evolutionary process. The OBSERVE system has proven itself as an economical and successful on board monitoring system technology demonstrator.